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THE EFFECT OF TWO SOIL TEMPERATURES ON THE YIELD AND WATER RELATIONS OF HEALTHY AND DISEASED BEAN PLANTS

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It has been pointed out in a previous article by the writer[1] that the bean plant infected by the root pathogene, *Fusarium martii phaseoli* varies considerably in its behavior under different conditions. These variations seem to occur even when the amount of infection is the same, and not only in different seasons, but on different fields during the same season. The criterion of the severity of the disease has been the effect on the yield of the crop. Part of this variation has been explained by the writer[1] on the basis of varying amounts of soil moisture. It has been shown that a difference occurred from 30 to 40 percent in the reduction of yield of affected plants on experimental plots during a wet season and a dry season. The inability of the plants with reduced root system to obtain sufficient water to produce pods was the primary cause under these conditions. As the plots were on different fields, other factors not understood might have contributed to this reduction as for example, mineral nutrition, soil temperature, etc. The effect of soil temperature on this disease has been dealt with by Reddick,[2] who has presented data indicating a greater reduction in yield from diseased plants at a soil temperature of 22° C. than at 34° C. No yield was obtained at 15° even on check plants. Reddick pointed out, however, that the uneven rate of growth of the host plants at the different soil temperatures made the data extremely difficult to analyze. Further work is necessary in order to determine correctly the reaction of the affected host plant under these varying conditions. For this reason the present investigation dealing with the water relations of the bean plant and the effect of soil temperature on such plants has been undertaken.

To obtain a clearer understanding of the problem under consideration some of the peculiarities of the disease should be noted first. The dry root-rot caused by *F. martii phaseoli* is mainly a root disease. The fungus never invades the host tissue above ground. Also, unlike many of the species of the genus *Fusarium,* it seldom causes wilt. This has led to the belief that the fungus does not produce substances which when carried to the plant parts above ground, prove toxic enough to cause noticeable injury. The root system of the bean is invaded and becomes dry, leaving only a few surface roots for the plant. As long as there is sufficient moisture in the soil, however, the root stub and these surface roots may supply the plant with enough water to produce a fair set of pods. Under dry conditions, however, the pods are the first parts of infected plants above ground to show injury. They shrivel and become dry. Lutman[3] presents data to show that the concentration of sap is less in bean pods than in any other part of the plant. Since this is the case, it is readily seen that when the plant needs water and is unable to obtain it from the soil in sufficient amounts, it will begin drawing its supply from the pods.

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[1] Burkholder, W. H. The dry root-rot of the bean. Cornell Agr. Exp. Sta. Mem. 26: 1003–1033. 1919.

[2] Reddick, Donald. Effect of soil temperature on the growth of bean plants and on their susceptibility to a root parasite. Am. Jour. of Bot. 4: 513–519. 1917.

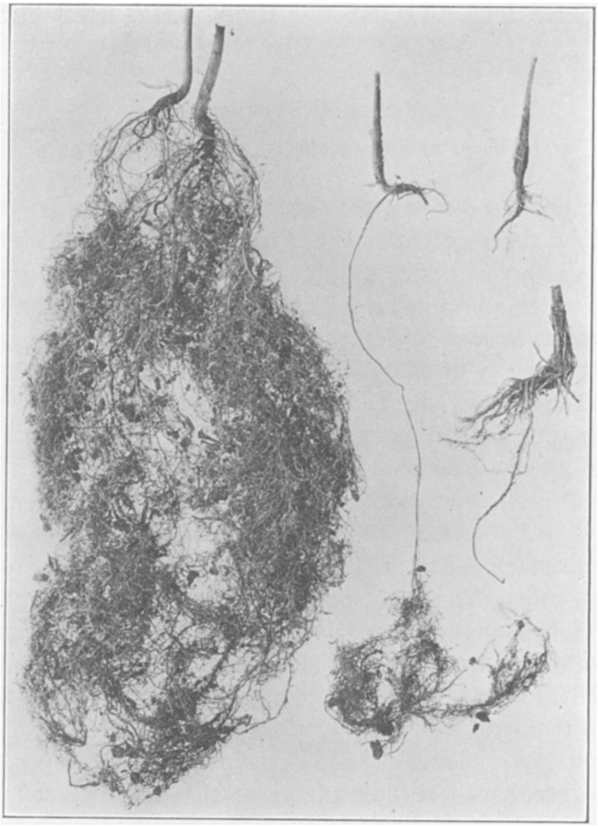

FIG. 1. *Fusarium* root-rot of the bean; showing on the left healthy, and on the right diseased, types of roots occurring in the experiment.

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[3] Lutman, B. F. Osmotic pressure in the potato plant at various stages of growth. Am. Jour. of Bot. 6: 181–202. 1919.

In planning the following experiments especially in reference to soil temperature, the methods employed by Reddick were followed in the main. Some changes, however, suggested by him were used.

Preliminary experiments were begun in the winter of 1918 and the experiments here recorded were conducted in the early months of 1919. Three temperatures were decided upon in these experiments. The lowest was 18° C. and was approximately the temperature of running tap water in the greenhouses during the months the experiments continued. The highest temperature was 33° C., at which beans will grow with little apparent injury, while 26° was chosen as half way between these two temperatures. During the progress of the experiments the plants grown at the highest temperature were killed inadvertently due to a break in the apparatus which raised the temperature for several hours. The data on these plants will not be given, although occasional references will be made to them. Since 18° and 26° C. are near the extremes of soil temperatures found to exist in the bean section of New York State during the growing season of this crop,[4] it is considered worthwhile to give the data on the plants in these two series.

Of the various external factors affecting plants, temperature is the most readily controlled. The temperature of soil in pot cultures has been held uniform in a number of ways,[5] the principles being the same in all cases, the methods varying in detail. In these experiments though a very simple and apparently crude device was used, the soil thermograph records taken throughout show but small variation. These variations were accounted for by temporary disturbances in the supply of electricity, always of short duration and so far as can be seen at present not affecting the results of the experiments in any way. Records for a week at a time do not show fluctuation exceeding 1° C. Galvanized tanks were placed in greenhouse benches with no special insulation, and filled with water. Hot water from a reservoir was let in through a valve which was activated by electricity under thermostatic control. Agitators worked constantly in all pans. The culture vessels used were glazed earthenware jars of one-gallon capacity.

To obtain a cool temperature in one of the pans, a steady stream of tap water was allowed to run through it continuously. During the months of February, March and April when the following experiments were conducted, the temperature of this water varied around 18° C. On a few hot days it rose for a short time to approximately 21° C., and in a few other cases fell to about 15° C. Continuous records were taken of the temperatures in all three pans by the use of Fries' soil thermographs.

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[4] Such records were taken in the bean fields during the seasons of 1916–1919 with continuous self-recording soil thermographs.

[5] Fitch, C. L. Health in potatoes. Colorado Agr. Exp. Sta. Bul. 216: 15–22. 1915.

Jones, L. R. Soil temperature as a factor in phytopathology. Plant World 20: 229–237. 1917.

The soil used to fill the jars was composed of two thirds rich garden loam, and one third sand. It was thoroughly mixed and sterilized before placing in the pots, care being taken to pack it as gently and evenly as possible. The soil moisture was controlled by the use of Livingston auto-irrigators. Two cups were placed in each pot, and the water was retarded by a column of mercury 2 centimeters in height. A bottle with a capacity of five hundred cc. was placed next to each pot, and filled with water from which the auto-irrigators drew their supply. About a week after the bean plants had pushed through the soil, the tops of the pots were sealed to prevent the evaporation of water. Pieces of heavy brown paper were cut to fit the tops, holes being allowed for the bean plants and the tubes of the auto-irrigators. These papers were then dipped into a mixture of hot paraffin and beeswax, and sealed on top of the pots with the same mixture. About the stems of the plants were placed paper tubes to keep the hot paraffin from coming in contact with them. These tubes were plugged with cotton.[6] Thus all the moisture that was lost by the pots was transpired through the leaves of the plants. Each day the amount of water lost from the bottles could be determined and thus the amount of water transpired by the plants in each pot. Tared culture vessels were used so that later in the experiment the soil moisture could be determined approximately by weighing the whole system.

In planting the beans in a glazed pot and covering the surface of the soil with paraffined paper it was possible that a poor aeration of the soil would result and cause injury to the roots of the plants. In the jars in these experiments, it is readily seen that there would be no intake or outflow of air due to fluctuations in temperature. However, the soil in the pots was light and with the use of the auto-irrigators it never became packed. Oxygen is not as essential for the roots of the beans as it is for those of some other plants. This was shown to be true by Noyes, Frost and Yoder[7] where none or but little injury resulted when the soil was saturated with carbon dioxide gas. No injury was noted to the plants in the check pots conducted in the following experiments. A very fibrous root system was produced, but since no unsealed pots were used, its cause could not be attributed to the lack of air.

In order to avoid having a vapor blanket encircle the plants and disturb their transpiration the water bath was covered. This was done by preparing a mixture of melted paraffin and beeswax, and pouring it over the surface of the water. It hardened quickly, and made a very satisfactory covering. It also aided in stabilizing the temperature in all pans surrounding the plants, preventing that in the warmer pans from rising considerably above that in the cooler one. Thus external factors governing transpiration were held as uniform as possible. A white, spherical atmometer, having a coefficient of .89 was run during the entire experiment. The readings of this instrument were made at the same time that the amount of water transpired by each pot was determined. This was between 9:00 and 11:00 o'clock every morning.

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[6] This was done primarily to exclude the fly, *Sciara coprophila* Lintner, the larvae of which cause damage to the roots of beans in the greenhouse.

Hawley, I. M. Jour. Econ. Entomology. June, 1919, p. 271.

[7] Noyes, H. A., Frost, J. L., and Yoder, L. Root variation induced by carbon dioxide gas addition to soil. Bot. Gaz. 66: 364–373. 1918.

The strain of beans used in the experiment was a pure line selected from the variety known as the Well's Red Kidney, and was obtained through the courtesy of G. P. McRostie of the Dept. of Plant Breeding. There were several reasons for using this variety in preference to any other. It frequently has been observed in the field that it is very susceptible to the dry root-rot, and besides, it is much more convenient to handle a bush bean in an experiment of this kind. In using a pure line too, there was less chance of variation in growth among the individual plants.

During the preliminary experiments it was observed that seed placed in a soil temperature of 18° C. germinated very slowly, and further development of the plants was greatly retarded. In the experiments conducted by Reddick, those plants grown at 15° C. were far behind the others and never produced any pods. It is possible that this is due more to a poor germination and start, than to the continuous growth under a low temperature. Bean growers claim that if they obtain a rapid germination and a good growth for the first week or so, they are more certain of a good crop. A number of investigators, too, have shown that any treatment of the bean seeds that affects germination, even advancing it, is liable to react unfavorably on the further growth of the plant. Kidd and West[8] have shown this to be the case when bean seed are soaked in water. For this reason it was thought best to germinate all the seed and grow them for the first week under the same conditions.

Likewise, it has been observed in germinating beans, and especially Red Kidneys that there is frequently a great difference in time of germination not dependent on external factors. For this reason a large number of uniform seeds were selected and put to germinate between moist filter paper. When these began to sprout, the seed coats were carefully removed, and four or five seeds were planted in each pot. After the experiment was under way, the number of plants in each jar was reduced to two. At the time of planting, all pots were inoculated with the nodule organism. Eight pots in each pan also were inoculated with *Fusarium martii phaseoli*. Four pots remained as a check. These beans were planted February 25. Inoculations were made at this time rather than after the jars were placed in their respective water baths for several reasons. When the soil is contaminated with the fungus before planting the seed, infection is more sure to take place than when a suspension of spores is poured about the roots. Infection too, is more likely to be uniform. Furthermore, it had been shown that the soil temperatures to be used did not affect greatly the infecting ability of the pathogene, and the problem was one of influence of soil temperatures on the progress of the disease. The soil temperature during the germination and first week of growth was such as is found in a greenhouse run at temperatures of 70° to 80° F. After the plants had expanded their first true leaves they were then placed in the soil temperatures under which they were to be grown to maturity. This sudden change in root temperature caused a slight flagging of the leaves of the plants at 18° C., but they quickly recovered and showed no other injurious effects. The change was not great for those plants to be grown at 26° C., and as expected, no effect was noticeable. Those plants raised to a soil temperature of 33° C. also showed no injurious effects.

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[8] Kidd, F., and West, C. The effect of soaking seeds in water. The Ann. of Applied Biol. 5: 1–10. 1918.

A more rapid development of the plants grown in the soil temperature of 33° C. occurred than at the two lower temperatures. The foliage was a darker green. Possibly, the nearest to normal growth in comparison with plants grown in the field was obtained in the soil temperature of 26° C. At 18° C. the plants were healthy but grew slowly. Although the different rate of growth in the three pans was very evident, there was not much variation in the blossoming. Beans grown in the soil temperature of 33° C., blossomed March 23 and 24; in soil temperature of 26° C., blossoming occurred from March 24 to 27; while at the lowest temperature, all plants blossomed on March 26 and 27.

On the night of March 23, the accident occurred that killed by high temperatures the roots of the plants grown in the warmest pan. Through this accident some interesting observations were made that have some bearing of the present problem and do not seem out of place here. On the morning of March 24, following the injury of the roots the leaves of the plants were flagging but soon recovered. Transpiration, however, remained normal. On the second day following the accident the transpiration was still approximately normal, but the lower leaves began to turn yellow. This yellowing of the leaves continued, progressing slowly up the plant until the top leaves were finally involved. A defoliation then occurred, followed by a decided drop in transpiration. On March 28, the roots of these plants were examined, and were found to have been killed to the surface of the soil. Between the soil and the paraffin paper the bean stem begun to send out small lateral roots. These were about one cm. or two cms. in length. A few plants that were allowed to remain in the jars soon began to develop new leaves and resume normal growth. From these observations, it seems probable that the dead roots were able to take in water from the soil and send it up to the parts above ground. Normal transpiration was checked only after the substances liberated from the dead tissue began to prove toxic to the leaves. That only a limited amount of the toxin is given off and that it is not continuous may be seen by the fact that the plants were able to recover.

It is possible that when *Fusarium martii phaseoli* attacks the bean root, a similar process occurs. The death of the root tissue is so slow, however, that a sufficient amount of toxin is not liberated to cause a noticeable effect on the leaves. The plant continues an apparently normal growth with the dead root aiding the few surface roots in the intake of water. Only in the decrease of available water supply is there a large decrease in yield.

The growth of the plants in the two remaining pans continued normal until harvest time. Those grown in soil temperature of 26° were somewhat larger than at the lower temperature. The check plants, too, in both pans had a more vigorous growth than the diseased plants, but in some cases, the difference was not readily discernable. No noticeable difference could be observed in the root growth of normal plants in the two series of soil temperatures. In both cases, they were fibrous and filled the pots well. Their weights, however, were not determined. Also no effect of the soil temperatures on the inoculated roots could be observed.

All individuals were harvested at as nearly a uniform state of maturity as possible. This stage was when all pods on a plant had turned yellow. The leaves, too, at this time frequently had all fallen. On the whole, the plants grown in the warmer soil matured earlier, but the difference was not marked. Inoculated plants, too, matured somewhat earlier. At harvest time, determination of the moisture percentage of the soil of each pot was made.

It was the intention of the writer to determine the dry weight of the roots and parts above ground. From this the water requirements of the plants could be calculated. It was more desirable, however, to obtain the weight of the seed, and since the leaves dropped before the seed matured, it was practically impossible to do both. Furthermore, it probably would be unfair to determine the water requirement of the plants based on roots which had partly decayed and fallen off. For these reasons the water requirements used here are based on weight of seed alone.

In table I, the weekly transpiration of these plants has been set forth. In table II, may be found the accumulated results of the experiment. In order to understand these data more thoroughly, certain factors should be explained that no doubt have a disturbing effect on the results. Pots 15 and 29 each had but one plant, so the amount of transpiration and weight of seed should not be compared with the other pots. Pot 14, although a check pot, does not compare favorably with the other checks of that series.

TABLE I. *Weekly Transpiration during Life Period of Healthy and Diseased Bean Plants at Two Soil Temperatures*
Check plants were healthy, others were diseased.

Pot	No. of plants	Mar. 7–13	Mar. 14-20	Mar. 21- 7	Mar. 28–Apr. 3	Apr. 4–10	Apr. 11–17	Apr. 18–24	Apr. 25–May 1	May 2–9	May 9–12
Evaporation[1]			75.1	104.7	89.1	87.0	69.1	121.7	100.1	108.6	42.8
Soil Tem. 26°											
13	2	236.3	363.7	451.7	595.3	769.4	647.8	942.0	533.8	332.7	88.0
14, Check	2	119.2	199.0	482.2	592.6	851.7	644.5	1,089.8	793.6	634.3	173.5
15	1	97.5	245.5	563.1	526.8	689.6	512.3	531.3	85.6		
16	2	457.0	483.0	288.8	97.2	9.2					
17	2	332.5	449.6	1,099.5	1,080.3	1,186.5	731.7	861.9	123.4		
18	2	291.6	393.3	317.1	232.5	68.9					
19, Check	2	339.9	536.6	1,284.7	1,296.7	1,563.5	995.5	1,568.5	643.0	90.5	
20	2	295.0	487.8	637.8	814.8	991.2	817.0	1,037.6	816.4	608.0	264.3
21, Check	2	410.1	609.5	1,338.0	1,509.9	1,415.7	1,118.2	1,674.6	1,096.9	485.3	164.2
22	2	136.3	193.7	442.4	499.5	540.2	228.6	74.4	65.4		
23	2	187.5	247.0	596.6	734.7	932.0	627.4	931.6	524.4	45.6	
24, Check	2	221.0	397.3	789.3	1,093.6	1,272.8	921.5	1,395.1	818.5	233.9	
Soil Tem. 18°											
25	2	245.2	365.9	540.7	789.8	919.5	696.3	910.9	628.1	99.2	
26, Check	2	214.1	236.2	518.7	756.4	907.1	707.8	1,110.8	811.4	304.2	
27	2	177.9	186.9	315.4	441.5	586.7	412.0	751.5	609.7	371.3	18.2
28	2	121.5	210.1	231.0	236.2	123.6	53.5	44.4	15.5		
29	1	78.4	153.9	272.3	369.4	250.4	207.2	231.1	204.3	155.6	52.8
30	2	189.1	225.3	346.1	460.1	544.2	512.2	836.7	636.6	398.2	26.5
31, Check	2	227.5	273.2	594.6	674.1	862.3	591.9	1,100.1	808.6	554.3	93.2
32	2	191.6	228.4	233.6	304.4	202.4	105.9	60.9	38.8		
33, Check	2	173.0	251.7	484.5	584.0	726.6	556.1	901.9	808.0	404.4	84.6
34	2	129.7	166.6	246.5	272.9	285.4	221.5	262.2	214.4	38.7	
35	2	131.0	177.2	179.3	249.0	251.9	241.7	379.8	275.8	265.9	116.7
36, Check	2	94.5	195.8	464.6	592.5	673.7	512.3	754.7	532.4	261.9	

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[1] Livingston's White Sphere Atmometer.

This may be accounted for by the fact that it had a very poor start. The auto-irrigator became plugged and the plants suffered from lack of water which caused wilting. Growth from then on was slow in comparison with the other checks. In the last column in table II, the degree of infection for each plant has been recorded. In only about one third of the pots could this be regarded as similar on both plants. The great variation that occurred in the other pots cannot be explained readily by the writer. With so many factors controlled, it was hoped that a greater uniformity would exist. This difference in infection, however, explains some of the irregularities that occurred in the transpiration and in the yield of the plants. Soil moisture determinations were not made until the seed was harvested. At this time all check pots were uniform. The inoculated plants, however, having lost a large percentage of their root system allowed more water to accumulate in their pots. That this accumulation occurred early in the experiment is doubted since other experiments were tested at blossoming time and did not show this to be the case.

The weekly transpiration of the two plants in each pot from the time they expanded their first true leaves, March 7, until harvest, has been recorded in table I. As is to be expected with a more vigorous growth, the transpiration was greater in the series run at 26° C. than in that at 18° C. In both series, however, the rise and fall of daily transpiration followed very closely the rise and fall of evaporation. This also may be seen in the weekly records. The maximum transpiration of all normal plants occurred during the weeks of April 4 and 18. This was the second and fourth week after blossoming. The intervening week between these two periods was characterized by a low evaporation. After the second period of maximum transpiration, the plants began to mature and on this account the use of water dropped off rapidly. When both plants in a pot were severely infected the maximum transpiration occurred at various times. Where there was light infection the course followed somewhat that of the normal plant.

It is probably unfair to average such data as are recorded in table II. The variations explained in a preceding paragraph would not be sufficiently neutralized with the small number of individuals used in these experiments. On the other hand, if differences are large enough no serious objections can be found in considering them in a general way. The following averages in this article apply to single individuals where two were grown in one pot. For this reason, pots 14, 15 and 29 have been eliminated. In soil temperature 26° C. check plants transpired throughout their life period on the average of 4216.0 grams of water, while inoculated plants transpired only 1945.8 grams. Here a reduction of a little over 50 percent took place. In soil temperatures of 18° C., an average transpiration of 2550.4 grams of water took place in normal plants; inoculated plants on the other hand, transpired 1410.6 grams of water. If pot 25 had been eliminated from the averages, a very close approach to a 50 percent reduction would have occurred here also. Pot 25, although one plant showed a severe infection, produced a normal yield of seed and maintained a high transpiration.

TABLE II. *The Effect of Two Soil Temperatures on Healthy and Diseased Bean Plants*

No. of pot	Inoculation	Date of harvest	Total water loss	Weight of seed	Water requirements per gr.	Infection	
						Plant 1	Plant 2
26° C.							
13....		5–11	4,960.7	10.29	482	Severe	Fair
14....	Check	5–12	5,580.4	8.28	673		
15....		4–27	3,251.7	6.10	533	Fair	
16....		4–4	1,335.2	0.0		Severe	Severe
17....		4–27	5,865.4	14.29	410	Fair	Light
18....		4–7	1,303.4	0.0		Severe	Severe
19....	Check	5–3	8,318.9	16.38	507		
20....		5–12	6,769.9	13.65	496	Severe	Light
21....	Check	5–12	9,822.4	14.96	656		
22....		4–30	2,180.5	4.07	535	Severe	Fair
23....		5–3	4,826.8	12.28	393	Severe	Fair
24....	Check	5–8	7,143.0	13.10	545		
18° C.							
25....		5–3	5,195.6	12.18	426	Severe	Light
26....	Check	5–7	5,566.7	14.16	393		
27....		5–7	3,871.1	8.87	436	Severe	Light
28....		4–27	1,035.8	0.0		Severe	Severe
29....		5–12	1,975.4	3.32	595	Severe	
30....		5–9	4,175.0	9.98	418	Fair	Light
31....	Check	5–12	5,779.8	11.56	499		
32....		4–30	1,366.0	.15		Severe	Severe
33....	Check	5–12	4,974.8	9.41	528		
34....		5–5	1,837.9	3.45	532	Severe	Fair
35....		5–12	2,268.3	4.00	567	Severe	Severe
36....	Check	5–8	4,082.4	12.10	337	Very light	

The yield of each pot also has been tabulated in table II. As is to be expected where the soil fertility was held constant there is a correlation between the yields and the amount of water used by the plants. A reduction of about 50 percent in yield is obtained in inoculated plants when the weights of seeds are averaged in the same manner as the amounts of transpiration was averaged. Pot 25, however, still disturbs a close approximation to the 50 percent reduction at the lower temperatures. In the series of plants kept at soil temperature 18° C. check plants gave an average yield of 5.9 grams of seed while diseased plants yielded but 2.75 grams. In soil temperature 26° C. a similar reaction took place. The average yield of the normal plant was 7.40 grams; inoculated plants averaged 3.89 grams. From these data, it appears that the soil temperatures used have very little effect on the disease, at least when the transpiration and yield are taken as the criteria. The temperatures used, as stated above were near the extremes of the soil temperatures found to occur during the growing season in the bean section of New York state. These records were taken for five consecutive years in this section. It may be concluded that the high and low soil temperatures have none or but little effect on the severity of the *Fusarium* root-rot.

The data, on the other hand, show that a low soil temperature decreases the yield of the healthy bean plant considerably. That is, 18° C. shows a decrease from 26° C. Reddick's data show an increase in yield at 22° C. over 34° C. From this the optimum soil temperature for beans can only be guessed at as about 22° C. and 26° C.

It might be wondered at here why a 50 percent reduction both in yields and transpiration occurred in these experiments when the writer has pointed out in the article mentioned before that only a slight reduction in yield occurs on inoculated plants when a sufficient amount of water is available in the soil. It is probable that a sufficient amount of water was available in these experiments. On the other hand, the plants were growing under abnormal conditions and did not as in the field produce numerous surface roots. This fact is possibly the principal cause of the low yields under these conditions.

The "water requirements" recorded in table II are based on the weight of the seed. Considerable variation is found to occur among them which possibly is to be expected since so many different conditions occurred among the plants. The figures, on the whole, appear to be somewhat higher in the 18° C. series. Very little work has been done on the effect of soil temperatures on water requirements. The work that has, as far as the writer is aware, shows no variation with soil temperatures. In these cases, however, the water requirements were based on dry weight of plants. In the soil temperature of 26° C. the inoculated plants required less water per gram of seed than did the healthy plants. This appears to be reversed in the 18° C. series. Wimmer[9] showed that the water requirements of sugar beets and celery is increased by attacks of parasitic nematodes. The explanation that is offered is that the diseased plants grow more slowly. The data set forth in the present article on water requirements in beans gives indications only as to the effect of the various factors concerned. The data are rather limited and should not be accepted as final.

CORNELL UNIVERSITY, 1920

[9] Wimmer, G. Nach welchen Gesetzen erfolgt die Kaliaufnahme des Pflanzen aus denn Boden? Arbeiten der Deut. Landw.-Gesellschaft. Heft. 143: 169. 1908.